The (p,n) Reaction on Cadmium Isotopes Leading to the Ground- and Excited-State Analogs

V. 9 The (p,n) Reaction on Cadmium Isotopes Leading to the Ground- and Excited-State Analogs

Murakami T.*, Orihara H., Nishihara S.*, Nakagawa T.*, Maeda K.**, Miura K.*** and Morita S.
Cyclotron and Radioisotope Center, Tohoku University
Department of Physics, Faculty of Science, Tohoku University*
College of General Education, Tohoku University**
Tohoku Institute of Technology***

As pointed out by French and Macfarlane[1], the charge exchange reaction populates selectively not only the isobaric analog state corresponding to the ground state of the target nucleus (GAS) but also those corresponding to its low-lying excited states (EAS). Satchler, Drisko and Bassel[2] have made a DWBA calculation of the (p,n) reaction leading to EAS, employing a deformed Lane potential as the interaction responsible to the transition. Their calculation has given cross sections which are smaller by more than an order of magnitude than experimental cross sections. Madsen et al.[3] pointed out that the two step processes, namely the (p,p') transition followed by the quasielastic charge-exchange transition and the quasielastic charge-exchange transition followed by the (n,n') transition, might be of essential importance for the (p,n) reaction leading to EAS. They have made a coupled-channel calculation and successfully reproduced experimental cross sections for the (p,n) reaction to EAS. In the present article, we present the experimental results of the (p,n) reactions on ^{110,114,116}Cd leading to GAS and EAS, and the analysis of them in which the two-step transitions to EAS are taken into account.

A 25 MeV proton beam was obtained from the AVF cyclotron at Cyclotron and Radioisotope Center, and neutron energies were measured by the time-of-flight method. A flight path of 24.6 m and a repetation time of beam bursts of 374 ns were used. Details of the experimental arrangements and data reduction procedures are described elsewhere in this issue of the CYRIC ANNUAL REPORT. The targets were prepared by rolling isotopically enriched cadmium metals, and their thicknesses were about 5 mg/cm^2.

Fig. 1 shows the energy spectrum of neutrons from the ^{116}Cd(p,n)^{116}In reaction observed at 60° relative to the direction of the proton beam. It is seen in this figure that in addition to GAS three EAS corresponding to the 2^+, 3^- and 4^+ vibrational states in ^{116}Cd are strongly excited. EAS corresponding to the 2^+, 3^- and 4^+ vibrational states in parent nuclei were observed also in the cases of (p,n) reactions on ^{110}Cd and ^{114}Cd. In every case, relative energies of these EAS with respect to GAS are in good agreement with the excitation energies of the parent states. The excitation energies of GAS and relative energies of EAS with respect to GAS obtained in the present experiment are listed in Table 1, where the Coulomb displacement energies from Ref. 4 are also given

for comparison. The spins and parities given in this table are those of the parent states and therefore those which the isobaric analogs are expected to have. Figs. 2 and 3 show respectively the neutron angular distributions for the transitions to GAS and those for the transitions to 2^+ EAS. The angular distributions were obtained by assuming in each spectrum a continuous background represented by a quadratic function as shown with a dashed curve in Fig. 1. Error bars attached to the experimental points stand for statistical uncertainties.

The curves in Fig. 1 are theoretical cross sections for the quasielastic charge-exchange transitions to GAS calculated with the code CHUCK; the dash-dot curve was calculated with optical model parameters given by Becchetti et al.[5], the solid curves with those given by Carlson et al.[6], and the dashed curve with those given by Patterson et al.[7] The last set of parameters was used in all the following calculations of the transitions to 2^+ EAS.

Using the code CHUCK, we have made three sorts of calculation of the (p,n) transitions to EAS corresponding to the one-phonon 2^+ state in the target nucleus: A) a calculation taking account of the one-step or direct transition only; B) a coupled-channel calculation taking account of two two-step processes, i.e. (i) the quasielastic trnsition to GAS followed by the transition to 2^+ EAS, and (ii) the transition to the parent state of 2^+ EAS followed by the quasielastic transition to 2^+ EAS; C) a coupled-channel calculation taking account of the two two-step transitions and the direct transition. The interaction potential

$$\Delta U = - R[\beta_2^{(0)} \frac{\partial}{\partial r} U^{(0)} + \beta_2^{(1)} \frac{\partial}{\partial r} U^{(1)}] \ , \qquad (1)$$

was assumed in these calculations, where β is the deformation parameter and U the optical potential. The superscripts (0) and (1) mean the isoscalar and isovector parts, respectively. The results of the calculations are shown in Figs. 3 and 4.

The solid curves in Fig. 3 are the cross sections obtained from calculation B with $\beta_2^{(0)}$ equal to the experimental β_2 for the Coulomb excitation of the 2^+ parent states given in Ref. 8. The dashed curves in Fig. 3 are the cross sections obtained from calculation C with $\beta_2^{(0)}$ equal to the experimental β_2, and with $\beta_2^{(1)}$ equal to $2\beta_2$, $3\beta_2$ and $4\beta_2$ for the reactions on ^{110}Cd, ^{114}Cd and ^{116}Cd, respectively. The solid curve in Fig. 4 is identical with the solid curve for the reaction on ^{114}Cd shown in Fig. 3. The dashed curve in Fig. 4 is the result of calculation C with $\beta_2^{(0)}$ and $\beta_2^{(1)}$ both equal to the experimental β_2. The dash-dot curve in Fig. 4 is the result of calculation A with $\beta_2^{(1)}$ equal to the experimental β_2.

The present analysis shows the importance of the two-step processes in the (p,n) transition to 2^+ EAS as pointed out by Madsen et al.[3]; the cross sections calculated by assuming only the direct transition are about 50 times smaller than the observed cross sections as shown in Fig. 4, while the coupled-channel calculations taking the two-step processes into account reproduce the observed cross sections fairly well. It is also noted that of the present coupled-

channel calculations the one taking account of the direct transition as well as the two-step transitions with $\beta_2^{(1)} > \beta_2^{(0)}$, which gives the dashed curves in Fig. 3, seems to best explain the observed cross sections for the transitions to 2^+ EAS.

References

1) French J. B. and Macfarlane M. H., Phys. Lett. 2 (1962) 255.
2) Satchler G. R., Drisko R. M. and Bassel R. H., Phys. Rev. 136 (1964) B637.
3) Wong C., Brown V. R., Madsen V. A. and Grimes S. M., Phys. Rev. C20 (1979) 59.
4) Harchol M., Jafte A. A., Miron J., Unna I. and Zioni J., Nucl. Phys. A90 (1967) 459.
5) Becchetti, F. D. Jr., and Greenlees G. W., Phys. Rev. 192 (1969) 1190.
6) Carlson J. D., Zafiratos C. D. and Lind D. A., Nucl. Phys. A249 (1975) 29.
7) Patterson D. M., Doering R. R. and Galonsky A., Nucl. Phys. A263 (1976) 261.
8) Stelson P. H. and Grodzins L., Nucl. Data A1 (1965) 21.

Table 1. Levels strongly populated by the (p,n) reactions on Cd isotopes

Target	J^π	energy[a)]	ref. 4)
^{110}Cd	0^+	13.49±0.05	
	2^+	0.67	
	3^-	2.09	
	4^+	2.3	
	$(0^+,2^+4^+)$	1.5	
		1.8	
		2.5	
		2.7	
		3.0	
^{112}Cd	0^+	13.41±0.05	13.386±0.07
	2^+	0.62	
^{113}Cd	0^+	13.35±0.1	
^{114}Cd	0^+	13.35±0.05	13.310±0.015
	2^+	0.56	
	3^-	1.97	
	4^+	2.38	
	$(0^+,2^+,4^+)$	1.3	
		2.8	
^{116}Cd	0^+	13.24±0.05	
	2^+	0.50	
	3^-	1.90	
	4^+	2.42	
	$(0^+,2^+,4^+)$	1.3	
		2.7	

a) The energies of 0^+ GAS are the Coulomb displacement energies, and those of EAS are the energies relative to GAS.

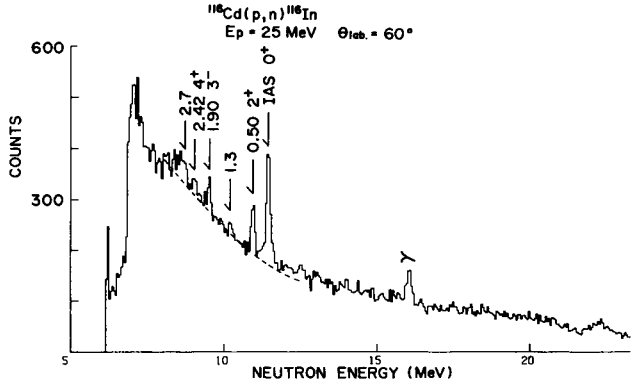

Fig. 1. Energy spectrum of neutrons from the $^{116}Cd(p,n)^{116}In$ reaction obtained from the time-of-flight measurement at a bombarding energy of 25 MeV and a flight path of 24.6 m. The dashed curve is an assumed background to the individual peaks.

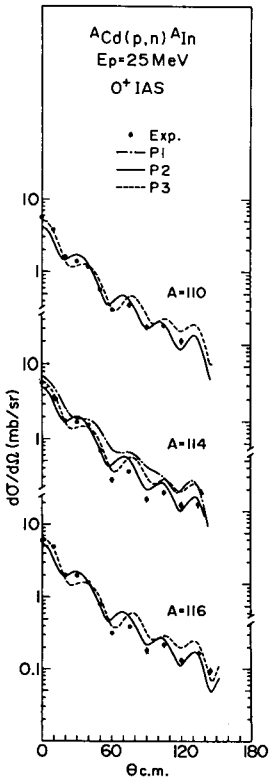

Fig. 2. Angular distributions for 0^+-GAS. The error-bars stand for statistical uncertainties. The curves are the cross sections calculated with three different optical potentials.

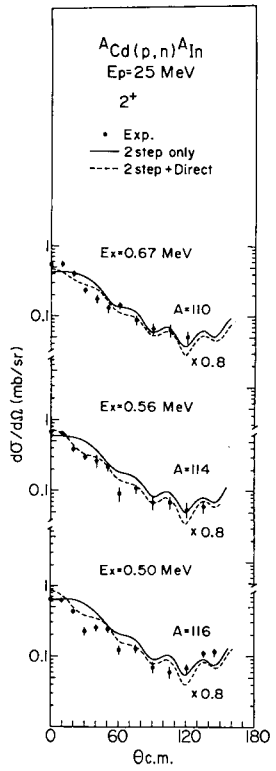

Fig. 3. Angular distributions for the (p,n) reactions to 2^+ EAS in ^{110,114,116}In. The curves are theoretically predicted cross sections multiplied by a factor of 0.8.

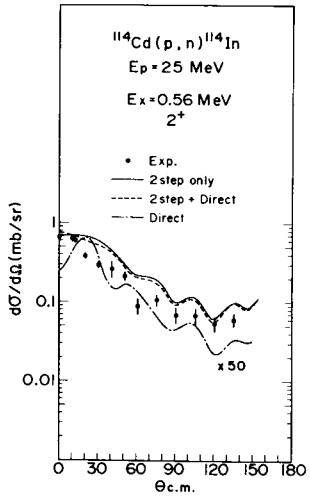

Fig. 4. Angular distributions for the (p,n) reactions to 2^+ EAS in ^{114}In. The curves are theoretical predictions.